

HF GROUND WAVE PROPAGATION OVER FORESTED AND BUILT-UP TERRAIN

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An integral equation method is presented for computing the vertically polarized field strength over irregular terrain which is covered with forest, buildings, or snow. The terrain cover is modeled as an equivalent slab, and a general computer code, WAGSLAB, is developed. Numerous special cases are treated analytically, and comparisons are made with numerical results from WAGSLAB.

Key words: flat earth; HF ground wave propagation; irregular terrain; mixed path; lateral wave, slab model; spherical earth; vertical polarization

1. INTRODUCTION

Integral equations (Hufford, 1952; Ott and Berry, 1970) have been found useful for calculating the ground wave field over irregular, inhomogeneous terrain. More recently Causebrook (1978a) has modified Hufford's integral equation to account for the effect of built-up sections along the path and has been successful in modeling MF propagation in the London vicinity. He assumed that the building heights were small compared to a wavelength, and he did not consider the effect of antenna height.

In this report, we extend Causebrook's general approach upward in frequency to the HF band where the building and forest heights are not necessarily small and the effect of the antenna height is important. The extension utilizes an anisotropic slab to model forest, snow, or buildings along the path. We modify Ott's (1971a) computer program (WAGNER) to include the possibility of a lossy, anisotropic, dielectric slab of arbitrary thickness over the ground. The slab parameters are allowed to vary along the path just as the terrain height and earth conductivity and dielectric constant are allowed to vary in program WAGNER. The source and receiving antennas can be located either within or above the slab, and only vertical polarization is considered. The same technique could be used for horizontal polarization, but the rapid attenuation makes horizontal polarization not useful for ground wave propagation.

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The integral equation approach that is described in this report is a point-to-point prediction method and should be most useful for frequencies below 30 MHz. For higher frequencies, the variability of the ground wave in time and space becomes large, and an accurate point-to-point prediction becomes difficult. A recent report (Hufford et al., 1982) describes an area prediction model for VHF, UHF, and SHF frequencies.

The organization of this report is as follows: In Section 2, the fields of a vertical electric dipole are analyzed for the dipole either within or above a uniform slab. The effective surface impedance and the height-gain functions are derived. In Section 3, Ott's previous integral equation (1971a) is extended to include a slab above the earth by using surface impedance and height-gain approximations from Section 2. In Section 4, a two-section path is analyzed both by Kirchhoff Theory and by the integral equation method. The analytical result from the Kirchhoff Theory is useful in its own right and also provides a good check for the revised integral equation. In Section 5, the values for the equivalent slab parameters for forests, built-up areas, and snow are discussed. In Section 6, specific path calculations are performed using the integral equation approach. Section 7 includes a summary and recommendations for further work. In Appendix A, both the integral representation and the asymptotic result are derived for the case where the dipole is located within the anisotropic slab. Appendix B includes the rather involved mathematical details of the Kirchhoff integration which is required for the two-section path analysis in Section 4. Finally, Appendix C provides a user's guide, a listing, and a sample output for program WAGSLAB which is essentially an extension of Ott's program WAGNER.

Throughout the report, we present propagation results in terms of a normalized attenuation function f which is the ratio of the actual electric field to twice the free-space field. This is done in order to emphasize propagation effects and to eliminate antenna effects. Thus f is unity for a flat, perfectly conducting ground. If some form of transmission loss is desired, it can be easily computed from the free space transmission loss and the magnitude of f .

2. UNIFORM SLAB MODEL

In this section, we analyze a uniform, anisotropic slab model for a vertical electric dipole source. The asymptotic results for the uniform slab model (Wait, 1967a) can be cast in a very convenient form where the total field can be factored into a product of twice the free space field times a ground-wave attenuation function times the height-gain functions for the source and observer heights. The attenuation function depends on the surface impedance for a layered medium in the